Feb. 6, 1968 K. E. RANKINS 3,368,120

MULTILAYER CONTACT SYSTEM FOR SEMICONDUCTOR DEVICES

Filed March 22, 1965

FIG. 1.

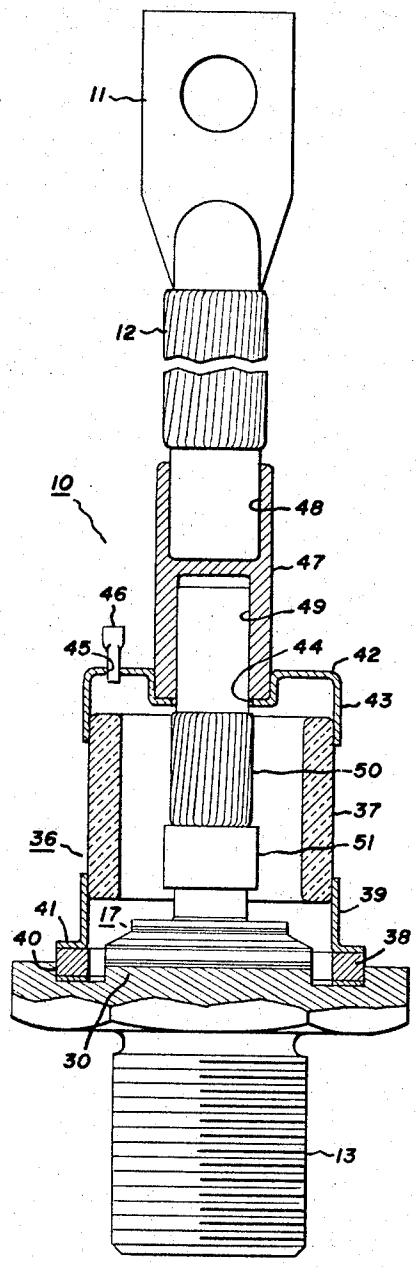


FIG. 2.

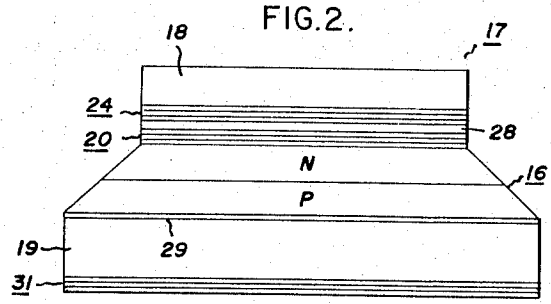
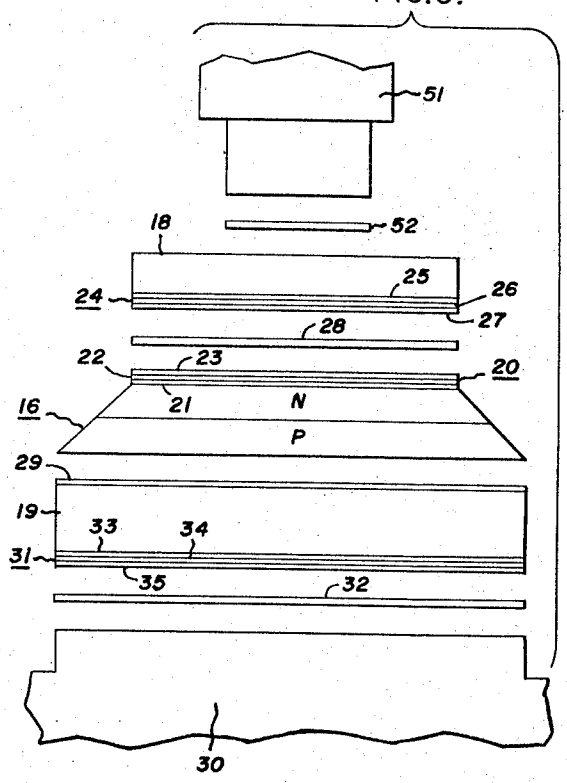


FIG. 3.



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MULTILAYER CONTACT SYSTEM FOR SEMICONDUCTOR DEVICES

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ABSTRACT OF THE DISCLOSURE

In a PN junction semiconductor device the semiconductor body is secured to one or more support plates by a solder, the adhesion of the bodies is improved by using a multilayer deposit preferably on both the contact member and the semiconductor body. The multilayers comprise a layer of nickel bonded directly to the bodies, a layer of iron bonded directly to the nickel and a layer of gold bonded to the layer of iron and the solder is applied between the layers of gold.

This invention relates to semiconductor devices of the junction type and more particularly to contact structures and means to form conductive connections to semiconductor bodies.

It is recognized that it is extremely important, but difficult, in many semiconductor devices to make electrical contact which provides good electrical and thermal conductivity and good mechanical strength. The problem is particularly acute when contact is to be made to thin diffused heat sensitive layers of semiconductive material (e.g. thin impurity diffused layers) and when location of the contact on the semiconductor surface is critical.

Prior methods of producing contacts on semiconductive bodies include conventional alloying or soldering techniques, pressure contacts with all their inherent drawbacks, plating to metalize the semiconductor and thin solder, plating the semiconductor and heating so that the plating material forms a solder or braze alloy and various arrangements of coating a contact element (sometimes multiple coatings) and then heating the contact element and semiconductive member so that the coating material (or materials) forms a solder or braze. When using conventional alloying or soldering techniques, the elevated temperatures required create problems with cooling stresses and degradation of device junctions. The cooling stress problem may be so severe as to cause pellet fracture. In addition, good wetting and control of contact location is a problem. Where the semiconductive body is metalized and then a solder used to make connections to the device, exact contact location is difficult to control and the elevated temperatures required to form a good joint can be detrimental to device parameters. When the semiconductive body is plated and then heated so that the plating material acts as a solder, degrading elevated temperatures are used and the plating material may react chemically with the semiconductor body unless the plating material is good. When gold is used for this purpose, the amount required to form a good bond makes very expensive contact. For the arrangement where a contact element is plated and then soldered or brazed to the semiconductor body, all the above disadvantages are likely to exist.

It is, therefore, an object of this invention to produce improved electrical contacts to semiconductive bodies.

The invention provides a contact structure for semiconductive bodies which gives good adhesion and contact with shallow penetration, provides accurate location of contact, etch resistance, and low temperature processing.

An improved contact arrangement and means for forming such contacts is described and claimed in the copending patent application, Ser. No. 346,868, filed in the name of Robert M. Hunter and David A. Fabel, "Semiconductor Contact Means," and assigned to the assignee of the present invention. Another invention which takes advantage of the general contact arrangement and method of contact formation of that application but affords an improvement for certain devices is described and claimed in copending patent application Ser. No. 355,539, filed in the name of Ronald A. Stott and John N. Frank entitled "Semiconductor Contact Means" and assigned to the assignee of this invention. This invention also takes advantage of the general contact arrangement and method described in the Hunter et al. application but affords an improvement especially for high current high power devices.

The objects of the invention are attained in accordance with aspects of the invention by providing a multilayer deposit on the semiconductive body as a contact means and in critical applications requiring low thermal fatigue failure rate a contact comprising a multilayer deposite is also provided on a support plate to which the semiconductor contact is secured. By selection of a combination of metals and thickness and order of layers, penetration and other contact parameters are controlled. In the preferred embodiment described here, the layers for both the support plate and semiconductor body contact comprise nickel, iron and gold.

The features which are believed to be characteristic of the invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

FIGURE 1 is a central vertical longitudinal section through a high current semiconductor rectifier constructed in accordance with the present invention;

FIGURE 2 is an enlarged elevational view of the rectifying elements of the rectifier of FIGURE 1; and

FIGURE 3 is an exploded and enlarged elevational view of rectifying elements shown in FIGURE 1.

In FIGURE 1, a semiconductor junction type rectifier is shown mounted in a sealed, self-contained unit which is referred to generally by the reference numeral **10**. The invention is shown and described in this setting because it is applied extensively to these devices. The device is called a rectifier because normally it conducts current in only one direction. That is, the device illustrated conducts current readily in a main conduction path between a lower threaded-bolt-like terminal and heat sink **13** through the body of the device to an upper flat lead terminal **11** on the main conductive lead **12** but offers a very high resistance to current flow in the reverse direction. For this reason, the upper terminal **11** and the lower terminal **13** are frequently referred to as the rectifier cathode and anode respectively.

The rectifying action is provided by the disc-shaped semiconductor pellet **16** (best seen in FIGURES 2 and 3) which is an element in the main conduction path. The rectifying semiconductor pellet **16** is a monocrystalline semiconductor material (silicon in this case) with a single junction between two layers of different conduction types. That is, one of the two layers (the lower layer) has an excess of free electrons (N-type conduction characteristics) and the other layer has an excess of positive holes (P-type conduction characteristics). In the particular rectifier unit illustrated the semiconductor pellet **16** is 800 mils (a little larger than ¾ inch) in diameter and about 9 mils thick. This thickness may be visualized by considering that it is a little thinner than the pieces which would result if a dime were sliced along one edge into four

equal parts. Semiconductor materials are very brittle, therefore, such a thin piece is extremely fragile. As a consequence, it is necessary to provide support and protection for the pellet **16**. This is done by "sandwiching" the pellet **16** in a protective diode assembly or rectifier sandwich **17**. This sandwich **17** is referred to as the active element of the rectifier.

Before continuing with the description it should be pointed out that the thin fragile semiconductor pellet **16** must rectify some very high currents and dissipate a great deal of heat. For example, the rectifier unit illustrated rectifies over 250 amperes and dissipates (generates) 250 watts of heat energy. Thus, the device may be subjected to extreme temperature excursions (−65° to +200° C.).

The sandwich or diode assembly **17** includes an upper backup plate **18** and a lower backup plate **19**. Due to the electrical conduction and heat dissipation problems, the upper backup plate **18** and the lower backup plate **19** are each made up of a material which has good thermal electrical conductivity. Due to the extreme temperature excursions to which the device may be subjected the materials are also selected so that their thermal coefficients of expansion closely correspond to that of the semiconductor material **16**. Tungsten is the material used in the device illustrated but molybdenum is also satisfactory.

In order to meet the critical requirements for low resistance contacts to the semiconductor pellet **16**, the present invention incorporates a system of multilayer deposited contacts which makes it possible to take advantage of the properties of several metals. At the same time, the system lends itself to a one cycle pass through a vapor plater and provides a contact which acts as a buffer to reduce transmission of stress from the device conductors (which are connected to the support plates **18** and **19**) to the device of pellet **16**.

Cathode contact **20** (see FIGURE 2) on the upper side of pellet **16** constitutes a preferred contact structure and is formed by a preferred method. In the embodiment illustrated here the first layer **21** (the layer on the pellet **16**) of contact is nickel and is approximately 0.05 to 0.01 mil thick, the second layer **22** (middle lamination) is an approximately 0.05 to .013 mil thick nickel layer, and the outer layer **23** is a layer of gold approximately 0.05 to 0.01 mil in thickness.

The preferred method of applying the cathode contact **20** is to mask the semiconductor material (either in pellet or wafer form) by conventional masking techniques (e.g., silicon dioxide) to leave exposed regions where the contact is to be formed. The semiconductor material is loaded in a commercially available vacuum vapor plating device. Charges of the plating metals are also placed in the furnace. The charges are in amounts and are placed at distances from the semiconductor material to be plated so that the plated layers each will be of the desired thickness. Calculations of amounts and placement can be made as taught in L. Holland, Vacuum Deposition of Thin Films, published by John Wiley and Sons, Inc., New York (1956) and many other articles found in CEC Bulletin No. 14–3 entitled "Bibliography on Metal Evaporation and Sputtering," Consolidated Electrodynamics Corporation, Rochester Division, Rochester 3, N.Y. For the device illustrated, the equipment is loaded with a charge of nickel to provide layer **21** on pellet **16** for contact **20**, and a charge of iron which ultimately forms the middle layer **22**, and a charge of gold which forms outer layer **23**. The charges are (as is conventional) placed in tungsten filaments which are fired in proper sequence (first nickel, next iron, and then gold) in order to provide the proper sequence of layers on the semiconductor material.

In the embodiment illustrated, a like contact **24** is provided on the surface of upper support plate **18**. This may be done at the same time the contact **20** is applied on the pellet **16** or in a separate operation. At any rate, a layer of nickel **25** is applied directly to one surface of upper support plate **18**, a layer of iron **26** is applied directly on the nickel **25** and a layer of gold **27** is deposited directly on the iron **26**. The thickness of each of these layers is comparable to the corresponding layer on the semiconductor pellet **16**.

Upper support plate **18** is secured to the pellet **16** by inserting a solder preform **28** (here a solder consisting of about 96% lead and 4% silver is used) and heating. The rectifier sandwich **17** is completed by attaching lower support plate **19** to the bottom of pellet **16**. In order to accomplish this, the upper surface of support plate **19** is provided, in this embodiment, with a thin layer **29** of aluminum which acts as the bonding solder between the two elements (**16** and **19**).

A good thermal and electrical connection is made between the rectifier sandwich **17** and the anode terminal (copper stud) **13** by mounting the lower support plate **19** directly on an enlarged disc-like head **30** on the copper stud **13**. This is accomplished by applying a lower contact **31** on the lower surface of lower support plate **19** and soldering this contact directly to the upper surface of stud head **30** using a solder prefrom **32** which is, in this embodiment, a solder of gold-tin as disclosed in United States Patent No. 3,160,798 in the name of W. F. Lootens and J. K. Flowers. The lower contact **31** on the lower support plate **19** is again a laminar contact laid down using vapor deposition techniques described above but is preferably made up of a layer **33** of nickel vapor plated directly on the support plate **19**, a layer of copper **34** vapor plated directly on the nickel layer **33** and a layer of gold **35** fired on the copper plating **34**. Thus, a good electrical and thermal contact is provided between the rectifier sandwich **17** and copper stud **13**. The copper stud **13** (anode terminal) is a good heat sink and constitutes a threaded bolt which allows the entire unit to be secured to a terminal board or other heat dissipating means. Further, to facilitate securing the device to a terminal board, the enlarged head portion **30** of the conductive stud **13** is provided with a hexagonal outer periphery to accommodate a wrench or other torque applying tool.

In practice, laminar contacts **24** and **31** are first applied to upper support plate **18** and lower support plate **19** respectively. The aluminum layer **29** is applied upon the lower surface of the pellet (silicon) **16**. The pellet **16** is then joined to upper surface of lower support plate **19** using the aluminum as a solder. The laminar contact **20** is then applied to upper surface of silicon pellet **16**. The assembly is then joined to the contact **24** on the lower surface of upper support plate **18** by the solder preform **28**. The outer periphery of pellet **16** is then beveled, as by grit blasting, and its surfaces etched and treated. Finally, the sandwich **17** is mounted down on the copper stud **13** by the gold-tin solder preform **32**.

The rectifying sandwich **17** is hermetically sealed in a housing **36** which utilizes the conductive stud **13** as the housing base. The side of the housing **36** is formed of a cylindrical ceramic member **37** which insulates the upper electrical connection (cathode **12**) from the anode **13**. The housing side **37** is sealed to the stud head **30** by means of an annular metal weld ring **38** and a cylindrical metal skirt **39**. The annular metal weld ring **38** is brazed in an annular groove **40** coaxially positioned in the top of stud head **30**. A lower outwardly extending flange **41** on the cylindrical metal skirt **39** is welded to the top of the weld ring **38** along its upper surface to provide an hermetic seal. The upper periphery of the skirt **39** extends up around the lower part of the ceramic cylinder **37** and a seal is made by conventional metal to ceramic seal techniques. The metal skirt **39** has some flexibility to accommodate expansion differential between the parts with temperature excursions.

The top of the housing is formed by metal header **42** which is more or less disc shaped with a downwardly extending cylindrical skirt **43** around its outer periphery. The skirt **43** extends down around the top of the ceramic side **37** and is sealed thereto by a conventional metal to

ceramic seal technique. The header is provided with a centrally located aperture **44** to accommodate a lead through for the main or cathode lead **12** and a smaller aperture **45** off center to provide for a tubulation **46**. The tubulation **46** provides a means of evacuating the housing. The lead through for the main cathode conductor **12** includes a cylindrical copper plug **47** which is sealed in the central aperture **44**. The plug **47** is provided with cylindrical apertures **48** and **49** in its upper and lower ends respectively to receive the lower end of the outer portion of the cathode conductor **12** and the upper portion of an internal part **50** of cathode conductor. The lower part (internal part) of the anode conductor **50** is connected inside the open part of a cup-like copper connector **51** as by crimping. This cup-like connector **51** is fixed to the top plate **18** of the rectifier sandwich as by a gold-tin solder perform **52** to complete the main current path through the device from the upper terminal **11** to the lower stud **13**.

While a particular embodiment of the invention has been shown, it will, of course, be understood that the invention is not limited to the particular embodiment since many modifications in the arrangements and instrumentalities employed may be made. It is contemplated that the appended claims will cover any such modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A semiconductor device of the rectifying junction type requiring external electrical connection thereto including a body of semiconductor material, and contact means secured to said body of semiconductor material, said contact means including a layer of nickel bonded directly to said body of semiconductor material, a layer of iron bonded directly to said layer of nickel, and a layer of gold bonded directly to said layer of iron.

2. A semiconductor device including in combination a body of semiconductor material, contact means secured to said semiconductor body, an electrical lead means including a conductive support plate and solder means securing said conductive plate to contact means, said contact means including a layer of nickel bonded directly to said body of semiconductor material, a layer of iron bonded directly to said layer of nickel, and a layer of gold bonded directly to said layer of iron.

3. A semiconductor device as defined in claim **2** wherein said conductive support plate has a further contact means including a layer of nickel bonded directly to said support plate, a layer of iron bonded directly to said layer of nickel and a layer of gold bonded directly to said layer of iron and said solder means secures said conductive plate and said semiconductor body at the said contact means for said plate and said semiconductive body.

4. In combination in a semiconductor device of the rectifying junction type, a rectifying sandwich assembly, said rectifying sandwich assembly being secured between conductive leads and including a semiconductor body and a pair of conductive support plates on opposite sides of said semiconductive body and conductively secured thereto, the means for securing at least one of said supporting plates to said semiconductive body including a contact means on said semiconductor body and solder means, said contact means including a layer of nickel bonded directly to said body of semiconductor material, a layer of iron bonded directly to said nickel and a layer of gold bonded directly to said iron.

5. The combination defined in claim **4** wherein the semiconductive plate secured to said contact means on said semiconductive body has a further contact means including a layer of nickel bonded directly to said support plate, a layer of iron bonded directly to said nickel and a layer of gold bonded directly to said layer of iron and said solder means secures said conductive plate and semiconductive body at the said contact means for both said plate and said body.

References Cited

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